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Suppression of intermodulation distortion in CATV system using Dual Parallel Mach-Zehnder Modulator

By

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Abstract:

Mach-Zehnder (MZ) modulator used in CATV system always produces some intermodulation distortion (IMD) that limits the optical transmission performance significantly. In this paper an analytical model of dual parallel Mach-Zehnder (DPMZ) modulator is proposed to ensure composite second order (CSO) products cancellation and composite third order (CTB) products minimization. We have determined the optimal input optical power splitting ratio with given values of electrode length ratio for a DPMZ modulator. It is found that the effect of CTB is in the allowable range if the input power splitting ratio and electrode length ratio of the primary and secondary MZ modulators are 0.88 and 2.0 respectively.

Keywords:

Composite second order, composite triple order, analog communication, intermodulation distortion and dual parallel Mach-Zehnder modulator

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1. Introduction:

Analog transmission of RF signals over the optical channel of a CATV system can be based on either direct laser modulation or an external modulator. Due to laser chirping, nonlinearity and other characteristic of direct laser modulators have poor quality. To overcome this limitation external modulator is used at laser output. The transfer function of MZ modulator is a sine wave function of the input voltage. For this reason, signal distortion is always found in a MZ modulator output. Two nonlinear terms generated by MZ modulator are composite second order (CSO) and composite triple beat (CTB) which severely limit the performance of the analog AM optical transmission system [1]. Many research works have been carried out to analyze and suppress the effects of CSO/CTB for analog optical transmission system [2-4]. An analytical and experimental study is carried out to compare the performance of direct- and external modulation in an analog optical transmission system [5]. A novel wavelength insensitive RF dc biasing technique is reported which significantly reduces the CSO [6]. Different methods for linearization of the MZM transfer characteristic have been developed. They improve the dynamic range of the input RF signals and keep the carrier to intermodulation distortion within the required limits. Simple models of a two stage modulator propose for increased linearity in [7-8]. In [8], the splitting ratios of input optical power and the input RF power values obtain using trail and error method and analysis the IMD performance up to sixteen channels.

In this paper, we have analyzed the DPMZ modulator and find out the input optical power splitting ratio with given electrode length ratio and optical modulation index for variable number of channels.

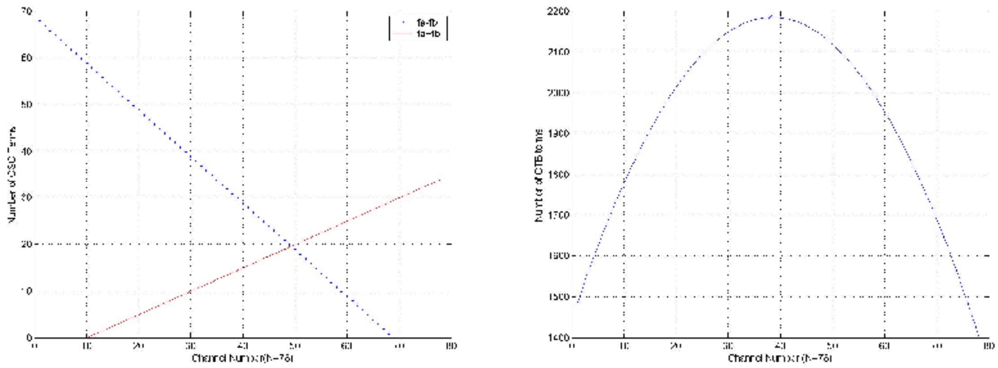
2. Theoretical Analysis:

2.1: Intermodulation distortion

Intermodulation distortion (IMD) takes place when more than one carrier interacts with each other in a non-linear system/device like MZM. Two type of IMD have serious effect such that CSO and CTB [9].The number of CSO products to appear in a RF channel can be determined by equation (1) follows and have shown in Fig.1 (a).

$$\begin{aligned} N_{CSO}(\text{bellow carrier}) &= (N-1)(1-((f-d)/(f_h-f_L)) \\ N_{CSO}(\text{above carrier}) &= (N-1)((f-f_L+d)/2(f_h-f_L)) \end{aligned} \tag{1}$$

Where N is the total number of RF channel, f is the frequency of the examined channel, f_L and f_h is the frequencies of the lowest and the highest frequency channel respectively and d is the carrier spacing.



(a) (b)

Figure (1): *(a) Composite second order (CSO) products vs channel number (b)Composite Triple bit (CTB) products vs channel number*

To calculate the number of CTB products at frequencies $f_i \pm f_j \pm f_k$ the following equation (2) can be used:

$$N_{CTB} = ((N-1)1/4 + (N-M)(M-1)/2) - (N/2) \qquad (2)$$

Where M is the examined channel, N is the total number of RF channel. CTB products vs channel number is shows in Fig.1 (b).

2.2: Dual Parallel Mach-Zehnder Modulator (DPMZM)

The basic configuration of optical DPMZM is shown below; it consists of a primary and secondary MZM those are connected in parallel optically and electrically.

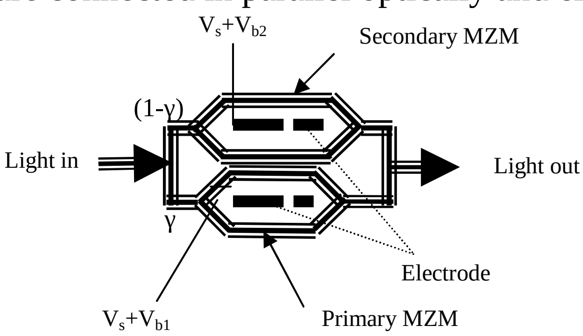


Figure (2): *Dual parallel Mach-Zehnder modulator*

The optical input power splits between primary and secondary in ratio $\gamma/(1-\gamma)$ the aim being to make the value of the optical power splitting ratio γ, thus minimizing the optical power loss. The secondary modulator electrodes are α times bigger than those of the primary modulator electrode. The transfer function of the DPMZM can be expressed as [10]

$$I_{out} = \frac{I_i}{2}\left[1 + \gamma\cos\left(\frac{\pi V_s}{V_\pi} + \phi\right) + (1-\gamma)\cos\left(\frac{\alpha\pi V_s}{V_\pi} + \phi\right)\right] \qquad (3)$$

where, V_s is the modulating RF signal voltage, V_π is the voltage required to change the output light intensity from its maximum values to its minimum values, I_{out} is the output light intensity and I_i is the input light intensity, ϕ is a static phase shift of the two arms of the modulator, γ is the input optical power splitting ratio and α is the electrode length ratio of primary and secondary modulator.

Assuming the modulating signal V_s is a sinusoidal voltage with angular frequency ω_i and amplitude A is superimposed on a dc voltage V_b thus we can write

$$V_s = A\sum_{i=1}^{N}\sin\omega_i t + V_b \tag{4}$$

Where, *N* is the total number of channel. Putting the value of (4) into (3) and becomes

$$I_{out} = \frac{I_i}{2}\left[\begin{array}{l} 1+\gamma\left(\cos\left(\frac{\pi A}{V_\pi}\left(\sum_{i=1}^{N}\sin\omega_i t + V_b\right)+\phi\right)\right)+ \\ (1-\gamma)\left(\cos\left(\frac{\alpha\pi A}{V_\pi}\left(\sum_{i=1}^{N}\sin\omega_i t + V_b\right)+\phi\right)\right) \end{array}\right] \tag{5}$$

Assuming , $\frac{\pi V_b}{V\pi}+\phi=\theta$, equation (5) can be written as

$$I_{out} = \frac{I_i}{2}\left[\begin{array}{l} 1+\gamma\left(\cos\left(\frac{\pi A}{V_\pi}\sum_{i=1}^{N}\sin\omega_i t+\theta\right)\right)+ \\ (1-\gamma)\left(\cos\left(\frac{\alpha\pi A}{V_\pi}\sum_{i=1}^{N}\sin\omega_i t+\theta\right)\right) \end{array}\right] \tag{6a}$$

$$I_{out} = \frac{I_i}{2}\left[\begin{array}{l} 1+\gamma\left(\cos\left(\frac{\pi A}{V_\pi}\sum_{i=1}^{N}\sin\omega_i t\right).\cos\theta+\sin\left(\frac{\pi A}{V_\pi}\sum_{i=1}^{N}\sin\omega_i t\right).\sin\theta\right)+ \\ (1-\gamma)\left(\cos\left(\frac{\alpha\pi A}{V_\pi}\sum_{i=1}^{N}\sin\omega_i t\right).\cos\theta+\sin\left(\frac{\alpha\pi A}{V_\pi}\sum_{i=1}^{N}\sin\omega_i t\right).\sin\theta\right) \end{array}\right] \tag{6b}$$

The expression can be simplified by assuming the modulation index per channel is small and by making the approximations $m=\frac{\pi A}{V_\pi}$.Using trigonometric and Bessel expression

$$I_{out} = \frac{I_i}{2}\left[\begin{array}{l} 1+\gamma\left(\begin{array}{l}\cos\theta\left(J_0(m)^N+2\sum_{\chi_i}\left(\prod_{i=1}^{N}\left(J_{\chi_i}(m)\cos\left(\sum_{i=1}^{N}\omega_i t\right)\right)\right)\right)+ \\ 2\sin\theta.\sum_{\lambda_i}\left(\prod_{i=1}^{N}\left(J_{\lambda_i}(m)\sin\left(\sum_{i=1}^{N}\omega_i t\right)\right)\right)\end{array}\right)+ \\ (1-\gamma) \\ \left(\begin{array}{l}(1+\cos\theta\left(J_0(\alpha m)^N+2\sum_{\chi_i}\left(\prod_{i=1}^{N}\left(J_{\chi_i}(\alpha m)\cos\left(\sum_{i=1}^{N}\omega_i t\right)\right)\right)\right)+ \\ 2\sin\theta.\sum_{\lambda_i}\left(\prod_{i=1}^{N}\left(J_{\lambda_i}(\alpha m)\sin\left(\sum_{i=1}^{N}\omega_i t\right)\right)\right)\end{array}\right) \end{array}\right] \tag{7}$$

$\sum_{\chi_i} = \text{even integer only}$, $\sum_{\lambda_i} = \text{odd integer only}$

Using equation (7), it is easy to show that the amplitude of the fundamental output carrier with frequency ω_i, $i = 1,2,....,N$, can be expressed as

$$\frac{I_{fund}}{I_i} = \left[\gamma J_1(m) J_o(m)^{N-1} - (1-\gamma) J_1(\alpha m) J_0(\alpha m)^{N-1}\right] \sin\theta \quad (8)$$

The amplitude of an output even order component with $\omega_i = \omega_j = 1$ and remaining indices become zero.

$$CSO = \frac{I_{2nd}}{I_i} = \left[\gamma J_1(m)^2 J_o(m)^{N-2} - (1-\gamma) J_1(\alpha m)^2 J_0(\alpha m)^{N-2}\right] \cos\theta \quad (9)$$

The amplitude of an output odd order component with $\omega_i = \omega_j = \omega_k = 1$ and remaining indices become zero.

$$CTB = \frac{I_{3rd}}{I_i} = \left[\gamma J_1(m)^3 J_o(m)^{N-3} - (1-\gamma) J_1(\alpha m)^3 J_0(\alpha m)^{N-3}\right] \sin\theta \quad (10)$$

It is obvious that when $V_b = 0.5 V_\pi$ and $\phi = 0$ thus θ become 90^0 no CSO product appears in the modulator output. So it is enough to calculate the C/CTB ratio in the central RF channel in order to estimate intermodulation distortion. On the basis of the relations obtained for the fundamental output signal and power of the CTB products the following formula for the C/CTB ratio can be obtain:

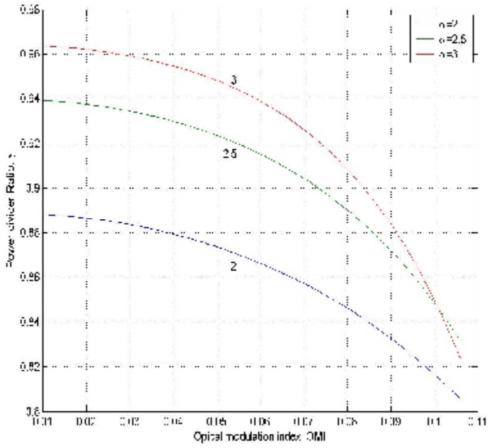
$$\frac{C}{CTB} = \left[\frac{\gamma J_1(m) J_0(m)^{N-1} - (1-\gamma) J_1(\alpha m) J_0(\alpha m)^{N-1}}{\gamma J_1(m)^3 J_0(m)^{N-3} - (1-\gamma) J_1(\alpha m)^3 J_0(\alpha m)^{N-3}}\right]^2 N_{ctb} \quad (11)$$

For calculating, assuming CTB product becomes 0. So parameter α and γ can be optimized using (10),

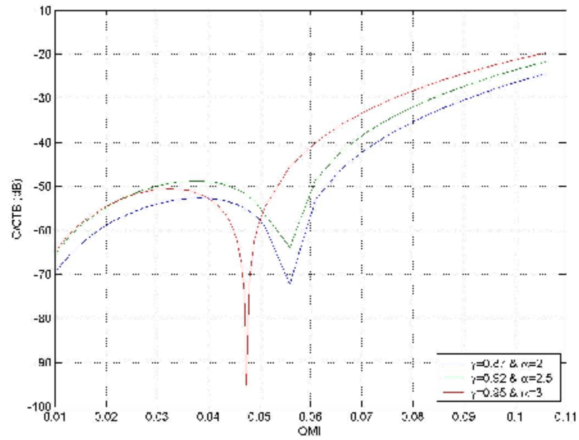
$$\gamma = \frac{J_1(\alpha m)^3 J_0(\alpha m)^{N-3}}{J_1(m)^3 J_0(m)^{N-3} + J_1(\alpha m)^3 J_0(\alpha m)^{N-3}} \quad (12)$$

3. Results and Discussion:

Expression of equations (8)-(12) can be used to generate a data-base for intermodulation performance of a DPMZM. The variation limits of the modulation index (m) must be determined. It is well known that increasing m improves the CNR, yet it does increase impairment caused by IMD too. Hence optimum operating values of m is a balance between noise and distortion. With CATV system range the m is 0.03 to 0.06 for admissible minimum value of the CNR and C/CTB parameters.



(a)



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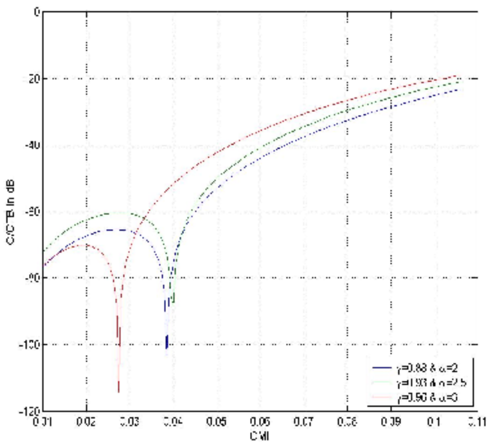

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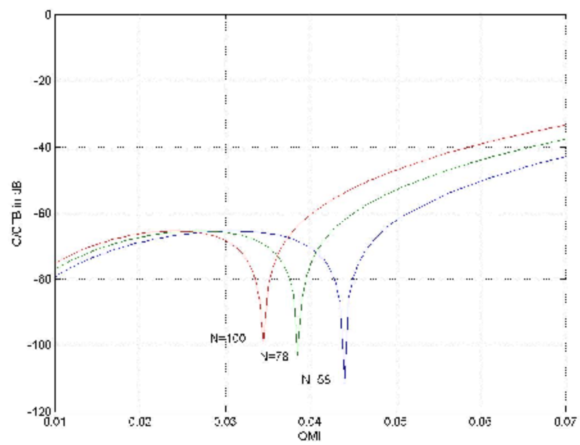

(d)

Figure (3): *(a) Optical power splitting ratio (γ) versus modulation index (m) under electrode length ratio α (b) Determination of the optimum value of parameter γ. referring, $\gamma = \gamma_{min.}$ (c)Determination of the optimum value of parameter γ. referring, $\gamma = \gamma_{max}$ (d) C/CTB versus modulation index for various number of channel at α=2 and γ=0.88*

In Fig.3 (a) the optical power splitting ratio γ is the function of the m for three values of α. For fixed value of α parameter γ is slightly changing with in admissible limits on m (0.03 to 0.06) given in Table.1.

Table (1): *The splitting ratio values versus α*

α / γ	2.0	2.5	3.0
γ_{max}	0.88	0.93	0.96
γ_{min}	0.87	0.92	0.94

To determine the optimum values of γ and α dependence of the modulation index m for a different number of transmitted RF channel has been investigated. In Fig.3 (a), obtained results are shown for 78 numbers of channels.
As seen from Fig.3 (b) & Fig.3 (c), the requirements for the maximum value of m and the minimum value of the optical loss in DPMZM are met simultaneously when α = 2 and γ=0.88. Then $C/CTB \geq 60\mathrm{dB}\,\mathrm{if}\,m \leq 0.045$, whereas if bigger values of γ and α (α=3.0 and γ=0.96) are chosen to minimize the optical power loss then the maximum permissible value of m is 0.034. For considering CNR high modulation index gives good performance over all system. IMD of the DPMZM signals for α=2, γ=0.88 and N=58, 78 and 100 can be estimate from Fig.3 (d). As for total number of channel increase C/CTB performance decrease and m also decrease.

4. Conclusions:

In order to optimize the parameters of the investigated DPMZ modulator conditions for the CSO products cancellation and for the minimization of the CTB products power have been used which account for the modulator operating mode, the modulation index and the number of RF channels transmitted. The investigations have shown that the CSO products cancellation occurs in the DPMZ modulator, if both modulators work in quardrature point. The best results for the modulation characteristic linearity and the minimum loss of the power in DPMZ modulator can be obtained when the optical power splitting ratio γ and electrode length ratio α are as follows: α=2.0 and γ=0.88.

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